

SMALL ORBITAL STEREO TRACKING CAMERA TECHNOLOGY DEVELOPMENT

Tom Bryan, Todd Macleod, Larry Gagliano
NASA Marshall Space Flight Center

Synopsis:

On-Orbit Small Debris Tracking and Characterization is a technical gap in the current National Space Situational Awareness necessary to safeguard orbital assets and crew. This poses a major risk of MOD damage to ISS and Exploration vehicles. In 2015 this technology was added to NASA's Office of Chief Technologist roadmap. For missions flying in or assembled in or staging from LEO, the physical threat to vehicle and crew is needed in order to properly design the proper level of MOD impact shielding and proper mission design restrictions. Need to verify debris flux and size population versus ground RADAR tracking. Use of ISS for In-Situ Orbital Debris Tracking development provides attitude, power, data and orbital access without a dedicated spacecraft or restricted operations on-board a host vehicle as a secondary payload. Sensor Applicable to in-situ measuring orbital debris in flux and population in other orbits or on other vehicles. Could enhance safety on and around ISS. Some technologies extensible to monitoring of extraterrestrial debris as well

To help accomplish this, new technologies must be developed quickly. The Small Orbital Stereo Tracking Camera is one such up and coming technology. It consists of flying a pair of intensified megapixel telephoto cameras to evaluate Orbital Debris (OD) monitoring in proximity of International Space Station. It will demonstrate on-orbit optical tracking (in situ) of various sized objects versus ground RADAR tracking and small OD models. The cameras are based on Flight Proven Advanced Video Guidance Sensor pixel to spot algorithms (Orbital Express) and military targeting cameras. And by using twin cameras we can provide Stereo images for ranging & mission redundancy. When pointed into the orbital velocity vector (RAM), objects approaching or near the stereo camera set can be differentiated from the stars moving upward in background.

Background:

Currently, there are 10 to 100 times as many small particles of orbital debris as there is medium to large debris in low earth orbits (more than 200K objects under 1100 Km altitude), thus creating less catastrophic, but much more probable hazards to satellites and vehicles being assembled in, or travelling through LEO. Despite the numerous threats of small orbit debris, it is very difficult to detect and track reliably with even modern or advanced ground radar. Current radar tracking of small objects in low earth orbits is hindered by the rapid orbit decay & corruption of distinct orbital paths for individual object correlation much like keeping tracking of a single minnow in a school moving in a stream at long distance. But detailed in-situ observation of debris moving toward ISS will allow calibration and correlation of ground radar and orbital debris models and MMOD requirements. ISS mounted debris tracking cameras that can then be deployed as a payload or sensor to other orbits where ground radar is even less sensitive.

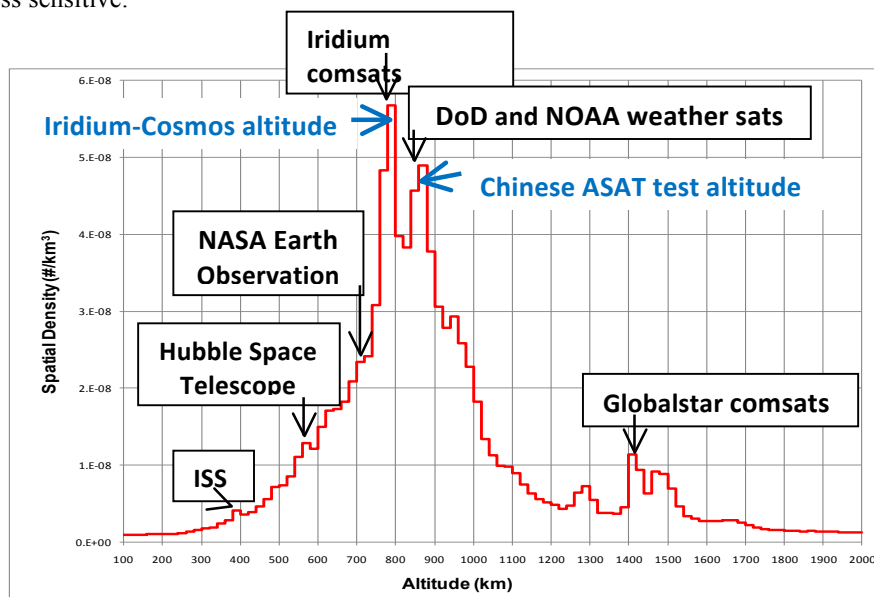


Figure 1: (Courtesy of Orbital Debris Program Office: J. C. Lui)

Current estimated Density of debris at various orbital attitudes with notation of recent collisions and resulting spikes.

Any exploration vehicle assembled in LEO must pass through this debris cloud and survive.

Large cross section, low thrust vehicles will spend more time spiraling out through the cloud and will suffer more impacts.

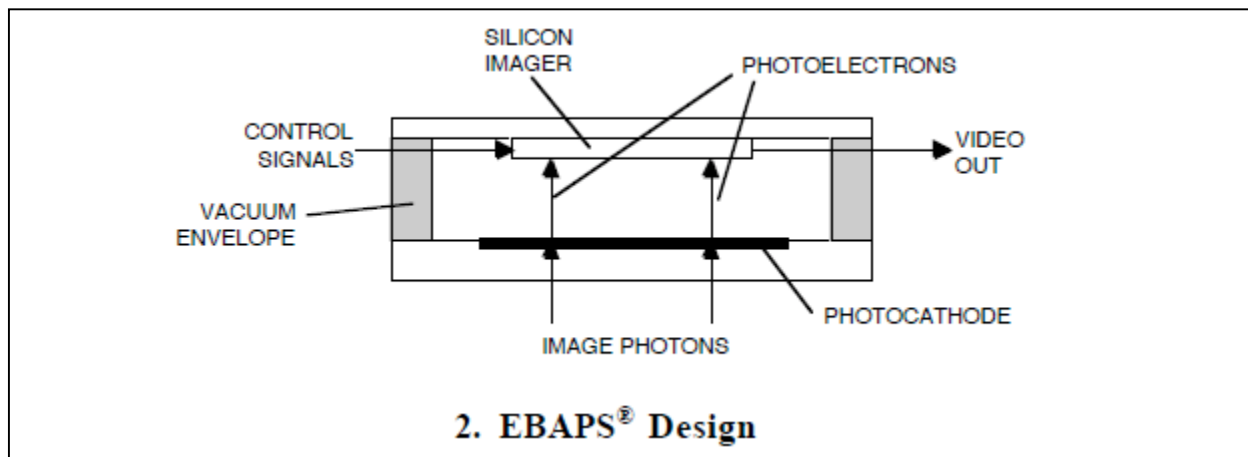
Better knowledge of small debris will improve survival odds.

Orbital Debris Tracking and Characterization has now been added to NASA Office of Chief Technologist's Technology Development Roadmap in Technology Area 5 (TA5) [Communications & Tracking] and is a technical gap in the current National Space Situational Awareness necessary to safeguard orbital assets and crews due to the risk of Orbital Debris damage to ISS & Exploration vehicles.

In response to the orbital debris risk, recent NASA Human Exploration mission designs currently utilize a highly elliptical orbit of 400 km x 80,000 km that allows support by a variety of existing launchers while minimizing exposure of Exploration vehicle to orbital debris with fast transits through high density orbits.

Problem Solution:

Sensor: Traditional orbital trackers looking for small, dim orbital derelicts and debris typically will stare at the stars and let any reflected light off the debris integrate in the imager for seconds, thus creating a streak across the image. The proposed Small Tracker will take a different angle on this problem by looking into the orbital velocity vector and letting the stars move "up" through the image while the co-orbiting debris moves toward the small tracker like a car in the opposing lane on a long highway at 15 kilometers per SECOND with the roadside scenery constantly moving by. But to be able to see the glint of sunlight from the small speeding bullets, we need to amplify their light with an intensified video imager such as the imager that is now incorporated into the Apache helicopter that transforms moonless nights into daytime scenery with only starlight (10⁻⁶ lux) and allows the pilot to recognize the faces of friend or foe. For our purposes, we will focus our image to a narrow field of view with a telephoto camera lens that has been ruggedized for launch and outer-space use.



Processing: Now we have a 2 M pixel image every 16 msec. that may have a pixel size orbital debris spot in a field of hundreds of stars from bright 2nd magnitude stars down to faint 11th magnitude stars, so we need to sort out a lot of spots in a hurry like panning for a nugget of gold. Since MSFC has had success with the design, manufacturing, programming, testing, and integration of a few generations of video guidance sensor technology that provided the first automated docking in US history and was used at ISS by the European Automated Transfer Vehicle for cargo and that is used by Lens-Crafters for automated eyeglasses measurements and MSFC is also a world recognized optics manufacturing facility for low weight ruggedizing optics for flight on ISS and for airborne Shuttle tracking, this orbital tracking imager will be an ideal match for MSFC experience, skills and facilities. One of the challenges of video guidance sensors is the real-time pixel processing into spots that can be sorted into targeted spots at 120 M pixels per second, that is solved by processing each incoming pixel as part of spot or not and then groups these lit spot segments into spots using the massively parallel processing capacity of advanced FPGAs.

The small tracker will see hundreds of stars and one or more orbital objects in every image, so by looking at the relative motion of the spots from image to image, it is simple to discriminate the moving spots (stars) from the stationary spots (debris) and pick-out some good (5th magnitude) reference stars. This spot data is also used to control the imager for and the reference star data is sent with the orbital object spot data along with a star tracker output that may be bore-sighted parallel to the small tracker. From 120 M pixels per sec, the FPGA and embedded processors will reduce the images down into several dozen spots that are <99% stars moving pass the Small Tracker Imager versus the two to five orbital objects per day zooming pass ISS and also control & synchronize the image for good spots & stars. For stereo, each small tracker will send common reference stars to align the stereo spot data.

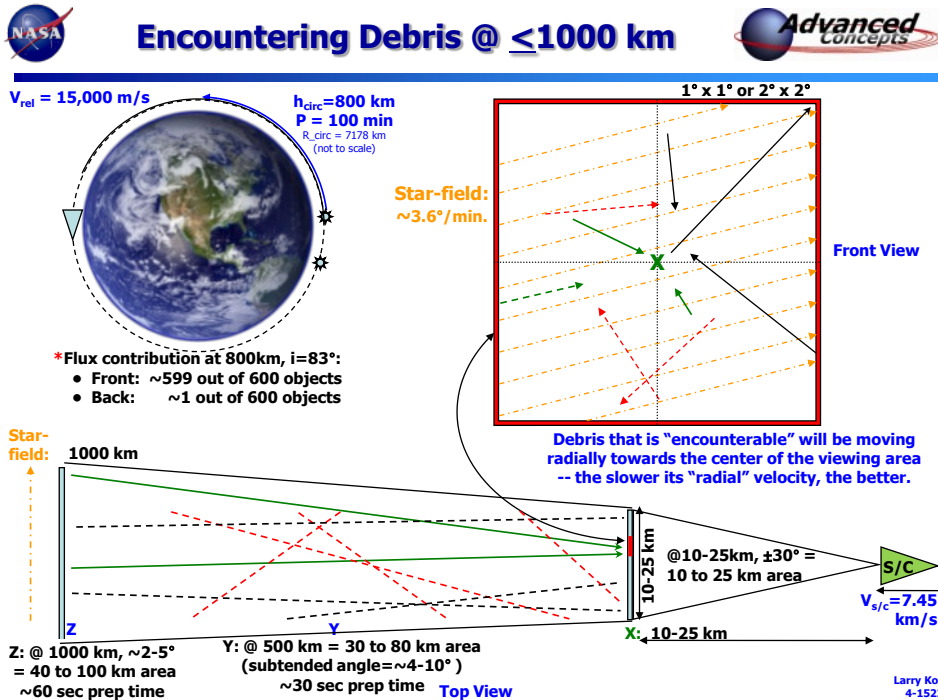


Figure 3: STARING images

Conceptual images from the Small Tracker using Amplified Real-time Imaging (STARING) when fixed on ISS looking toward the orbital velocity vector.

The Small Tracker will see Stars and other celestial objects "rise" through its Field of View (FOV) at the rotational rate of its orbit, but the glint off of orbital objects will move through the FOV at different rates and directions. Debris on a head-on collision course (or close) will stay in the FOV at ~ 14 Km per sec.

The Small Tracker can track at 60 frames /sec allowing up to 30 fixes before a near-miss pass.

A Stereo pair of Small Trackers can provide range data within 5-7 Km for better orbit measurements

Ground Testing: Once calibrated, the Small Tracker Imager can limit its output to the objects zooming past and some reference stars to use for precise tracking data and alignment to parallel spot data from the other stereo Tracker imager. One other variable that will have to be analyzed and verified is the optimal rotation of the image to the orbital pointing that will minimize pixel & spot processing versus debris discrimination. Tests will use a Dynamic Star Field Simulator that generates a high resolution image of the background stars and one to three small orbital objects (used to check Cube-sat star trackers) and perhaps some real-time star camera testing mounted to MSFC's Lunar Impact Telescope Observatory will verify the control and performance of the amplified imager, pixel-to-spot FPGA processing, and the orbital object discrimination algorithms. With successful testing, the Small Tracker using Amplified Real-time Imaging (STARING) design would be ready to transition from breadboard to an ISS external payload.

Prototype & Proto-Flight Testing: After learning everything possible from an affordable laboratory breadboard, a flight style prototype must be designed, analyzed, and fabricated in order to perform flight packaging and environmental testing, including better heritage components. Another concern that must be address at this point is proton and neutron radiation performance for the planned mission orbit and inclination. Before redesigning (parts, optics, layout, operations) after performing these radiation expensive and time consuming tests, good analysis and vendor & user research may save time and money. After the final form, fit, and function (including the physical, electrical, data, and optional reference start tracker interfaces) configuration is agreed to, the environmental testing can be planned and done as well a final performance ground testing to have a one or two proto-flight sensors ready.

Flight Integration: The small tracker(s) will be built to attach to an LEO host vehicle that provides an unobstructed mounting place looking into the velocity vector with power and two way data transfer \ communications to the operator on the ground. If ISS is selected as the first host orbital platform, there are a number of possible external mounting opportunities and with its small footprint, there are many secondary payload possibilities with relaxed angular and thermal requirements. The small tracker would be integrated at KSC or the primary payload integration site before loading into cargo vehicle for the trip up to and robotic placement onto the ISS exterior. Other possible flight experiment possibilities include mounting the small tracker to a prepared mounting site on an external payload after transfer out of the JEM airlock, mounting a suitable host satellite before launch (such as Iridium II), or deploy on a small dedicated low cost satellite with de-orbit capability.

Ground Data Processing: for the small trackers, the primary ground control function besides initialization and possible updates, is to schedule observation times to account for sun exclusion and host vehicle operations. And with the small tracker only needing to send star tracker data, reference star spots and debris spot data when debris is tracked, the host vehicle can store and forward the data at a convenient time or just include the trickle of data from the tracker(s) in its telemetry in real-time. Once the tracker data is screened, the star tracker data is used to determine when and where in the host platform's orbit the debris was sighted and if enough debris data points are collected, the trajectory and size is estimated. For stereo debris spot data, additional analysis using common reference star spot data is used to estimate the disparity between the debris spots in the FOVs of the two characterized trackers for range and velocity estimations. The debris data will be incorporated into the NASA Debris Density Models.

Status and Future plans:

Parts of the small tracker concept are currently available (older intensified camera and both the dynamic star field simulator and the Lunar Impact Observatory). An internal research project proposal is being evaluated for down select and there are low cost FPGA development boards and SLR camera lens that the concept can validated with COTS components and some custom interface boards and firmware. Future activities are still under review.

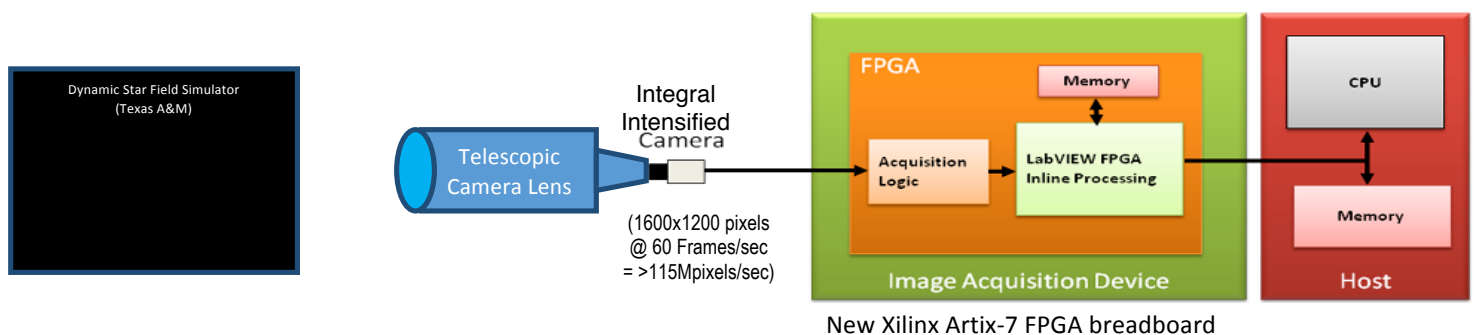


Figure 4: Small Tracker using Amplified Real-time Imaging (STARING) sensor proof of concept